NAG 2-471

AMES GRANT
IN-05-CR
142319
33P

1 FINAL REPORT

1.1 Title (W)

December 6, 1987

Conceptual Final Paper on the preliminary design of an Oblique Flying Wing SST

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(NASA-CR-182879) CONCEPTUAL FINAL PAPER ON THE PRELIMINARY DESIGN OF AN OBLIQUE FLYING WING SST Final Report (Van der Velden (Alexander J. M.)) 33 p CSCL 01C

N88-22891

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1.2 Abstract (W)

A conceptual Oblique Flying Wing Supersonic Transport Aircraft (from now on referred to as OFW, or "surfplane" because of its shape) was first proposed by dr. R.T. Jones in 1957 and was published by mr. Lee (ref. 13).

In the spring of 1987 the author and dr. Jones met in Los Altos, and discussed its reintroduction in view of the emerging technology of artificial stabilization. This study resulted from that discussion.

This paper is based on a performance and economics study of a M2 B747-100B replacement aircraft. In order to fairly compare our configuration with the B747 an end sixties structural technology-level is assumed.

It is shown that a modern stability and control system can balance the aircraft and smooth out gust and that our configuration equals or outperforms the B747 in speed, economomy and comfort.

1.3 Nomenclature (D)

	Description	dimension
BPR	Bypass ratio	
C	Climb speed	m/s
CLn	Lift coefficient normal to leading edge	
CM¼n	Normal pitching moment coefficient	
DE	Design empty	
h	altitude	m
L/D	lift-to-drag ratio	
M	Mach number	
mgg	Maximum gasgenertor massflow	kg/s
Mn	Mach number normal to leading edge	
OE	Operating empty	
OPR	Overal pressure ratio of compressor	
S	Wing planform area	m^2
s	distance	
t/c	thickness to chord ratio	
TET	Turbine entry temperature	K
tmax	maximum external thickness	m
Tto	Takeoff thrust	N, kgf
VEAS	Equivalent airspeed	m/s
VEASn	Equivalent airspeed normal to leading edge	m/s
Wp	Payload weight	kgf
Wto	Takeoff weight	kgf
α	angle of attack	°
σmax	material strength	N/mm^2
θ	angle of pitch	°
	¼ chord wing sweep angle	
	specific thrust	s
	overal engine efficiency as used in the Brequet formula.	

1.4 Principal Characteristics of the OFW (W)

The oblique supersonic flying wing as presented in the three-view in fig. 1a synthesizes three of the most promising orphans in aeronautical history:

1) The oblique wing: Proposed for the first time shortly after world war two by Robert T. Jones, this adaptive wing concept provides high lift-to-drag ratios at all speeds and therefore greatly increases the low-speed performance for aircraft designed at high speeds.

2) The flying wing and distributed load aircraft: Around the WOII period serveral designers like Lippisch and Burnelli and Northrop saw the advantages of flying wing aircraft. Such aircraft had higher cruise Lift-to-drag's and lower empty weights due to the reduced wing bending moment, however stability and control considerations prohibited their further development (ref.4)

3) The supersonic passenger aircraft: The supersonic passenger aircraft was in the focus of public attention during the sixties and mid-seventies. However the economic failure of Concorde and the SST led to the abandonment of the idea of commercial supersonic flight even though everyone recognizes the importance of reducing the current longhaul flighttime.

To aid the introduction of the Oblique SuperSonic Transport Aircraft it is designed as a successor of the B747-100B with 1970's and 1980's technology. It scheduled to be introduced in the first decade of the next century and should operate the ranges from 2000km up to 11000km with competitive direct operating costs.

This specification has been determined in accordance to Kuchemann's analysis of the motivation to travel (ref. 10/13), and the existence of an market segment for the aging B747. Taking a maximum daily time to travel of six hours, a Mach 2 OFW aircraft could serve 3/4 of the theoretical market economically.

(Note: The theoretical market is defined as the unconstrainted global demand for transportation irrespective of cost, see ref.10)

1.5 Description of the baseline design (W)

In the baseline configuration accommodates 462 passengers and 16 cabin crew who can be seated at a 35" pitch, twelve abreast. Apart from the cylindrical shell the the interior resembles that of a wide body airliner with a typical aisle height of 1.92m (6'3"). (fig 1a)

The baseline passenger cabin has no windows, but will be equipped with small flat high resolution LCD TV-screens for each seat block. Optionally, windows could be installed in the roof or in the floor near to the support structure. (fig. 1b,c)

Another deviation from the wide-body standard is the cockpit. In view of the oblique wing characteristics it does not make sense to design a protruding cockpit structure as suggested in ref. 13. Instead, space is provided on the left end of the cabin to house two pilots. (fig.2) The pilot will have a a very good visibility during approach and climb. However his field of vision is 70°left 70°right instead of 135°left 30°right as is recommended by the FAR 25.777.

One of the classical objections agains the flying wing, namely that it does not have stretch potential, is not true for our baseline configuration. We can simply add center cabin sections of the maximum thickness. It can be easily shown that in doing so we will even increase the L/D of the configuration.

The wing has an elliptic planform with a near elliptic spanwise relative thickness distribution, resulting in minimum wave drag for a given volume. (ref.2) The provisionally designed airfoil (ref. 8) has a maximum section thickness of 14% and a maximal CLn of 0.8 at a normal Mach number of 0.7.

In order to obtain an elliptic spanwise lift distribution, the elliptic wing planform must have a uniform distribution of lifting pressures, even at large angles of yaw. This can be realized by suitably twisting the wing along the span. For an oblique wing with an ellipse ratio of ten the optimum wing warp is descripbed in ref. 4.

Under the initial cruise conditions of M2 and 15500m the no-drag rize CLn for maximum L/D would be 1. New airfoils such as the OW-7-10 do reach these high lift coefficients at supersonic cruise, but Kuchemann (ref. 11 pp107) and my own optimization showed that a value of 0.7 gives the maximum payload to maximum takeoff weight ratio.

The thin airfoil theory of ref. 4 was used to optimally chose the airfoil geometry for minimal trim drag ($CM_{¼}=-0.056$) and minimal pressure drag ($CL_i \approx 0.7$)
The author found that the mean line distribution that best fitted qualities was a=0 distribution (see ref. 4 pp74 for definition). A NACA0014 basic thickness distribution with maximum thickness at 30% was added to accommodate the passengers optimally.

The OFW has a conventional monocoque and honeycomb structure using the aluminium alloy RR.58-AU2GN developed for Concorde which showed good maximum stress and fatigue qualities at high temperatures (ref. 7) We can expect an 15000h increase in airframe life with respect to Concorde's 45000h by the limitation of the Mach number to two which reduces the equilibrium skin temperature from 130°C to 100°C/373K.

To enable the structure to carry the loads of pressurization while maintaining a near unobstructed 'wide body' cabin , ceiling to floor connectors are placed at 3m (10ft) intervals. Such connectors could be placed at each side of the center seat block.

In an analysis carried out by the author it was found that such a structure of supported AU2GN-honeycomb pannels would be no heavier than a multibubble faired over conventional design but would offer a far more spacious and flexible cabin layout.

The nacelles can be pivoted over a 53° range and are distributed optimally along the span. In view of the limitations of the artificial stability and control system the nacelles had to be placed as far forward as possible, while synergistics, cabin noise and aerodynamic considerations dictated the placement outside the passenger cabin. To increase one-engine out yaw control and to minimize the wave drag and wing stress the engines were podded in four nacelles. To minimize fire danger in case of a crash landing the pods were placed beside and not underneath the fuel tanks.

The configuration is powered by four 250KN engines of conventional design with a core maximum massflow of 187 kg/s. These characteristics could be obtained from a refanned Rolls Rocye Olympus or a double scale GE F101/110. The inlets are of the two-shock three-dimensional mixed compression type.

The undercarriage has six legs with four 40"x14" (12bar/170psi) tires each. Even though we have a distributed load undercarriage the present layout still has a rigid runway LCN of 79. In view of the short TO field length we could consider redesigning the legs so the OFW could operate from the same runways as the B757. In this way we would increase the number of possible destinations by a factor five.

Table 1 will give more detailled technical information of the OFW design.

1.6 Optimization of the baseline design (W)

To size the wing and the powerplant the author has chosen the Wp/Wto fraction as optimization criterion. In ref. 15 it is considered as the most important indicatior of aircraft economy.

But we also have to recognize that there are constrains to our configuration, the most important are : (ref. 2)

a- Specification; basic B747-100B, the configuration has to accommodate 450+ passengers over a 9000km range at M2. The most important derived constraint for the OFW is the minimum required height dimensions of the cabin so we can actually seat the passengers. An OFW as described in the previous chapter would have to have maximum center thickness of least 2.15m. If we are to have sufficient cabin volume to seat 450 passengers the wing size should be at least $1461m^2$.

b- Technology (database) availability
Both limited access to information and actual limitations of the available techonology can limit our optimization process. The following technology levels were assumed readily available today:

- Structural: Conventional AU2GN honeycomb, $\sigma max=400N/mm^2$ able to withstand design maximum Mach number of 2, design Maximum Dive Mach number 2.1 and an maximum equivalent airspeed of 226m/s for an airframe life of 60.000h or more.

- Aerodynamics: A $(t/c)max=14\%$ for a $CLn=1$ and $Mn=0.7$ are the the current state of the art, however some allowance, say a 20% reduction of CLn, is needed to shape the airfoil to minimize trim drag and optimize usable volume.

- Powerplant, conventional BR=1 fan design with mixed gasflow, TET 1700K, OPR=11 with contemporary isentropic efficiencies and a gasgenerator airflow around 185 kg/s if we assume to use a refanned RR Olympus.

c- Airworthyness requirements; The aircraft has to comply with the FAR 25 airworthyness requirements and the FAR 36 stg 3 noise regulations. A direct result of the compliance with the noise regulations is the impossibility to use a BPR smaller than 1 even if variable cycle engines were used.

Using the above criteria we were left to select the optimum wing geometry. Contrary to conventional wing planform sizing it is unnecessary to chose the optimum area of the wing planform. It is not hard to understand that the minimum wing area that can provide seating to the passengers ($S=1461m^2$/ $V=1563m3$) is the optimum.

We are now left to choose the wing ellipse ratio and the powerplant size. Fig. 3 shows the iso-Wp/Wto lines for varying T/W and ellipse ratios. Within the constraints, an ellipse ratio of 8 and a T/W of 0.34 is the optimum.

At start cruise the powerplant would have to have a specific thrust of 40s for BPR=1. If we look at fig. 4 we see that it can be achieved by taking different combinations of TET and OPR. As can be inferred from the graph the maximum Wp/Wto-ratio occurs with a TET=1700K and OPR=11. Not surprizingly an OPR of 11 is also used in other supersonic engines.
For this combination the subsonic and supersonic propulsive efficiencies are high while the turbomachinery (thrust) losses are near minimal, maintenance costs acceptable and engine weight low.

1.7 Aerodynamic and operational characteristics (W)

In fig. 5 the effects of Mach number variation of maximum L/D and engine efficency areas shown. In table 2 the drag breakdown for Mach 2 cruise is given. The maximum aerodynamic efficiency at cruise is above 10, while at subsonic speeds values above 20 can be reached.

The weight breakdown for the harmonic range and design payload (462pax/9000km) is given in Table. 3. Notable is the low structural weight.

To take off the wing angle of incidence is set at about 4° normal to the leading edge by adjusting the gear. Minimum allowable wing sweep is limited by the vertical tailvolume

The takeoff and climb performance is better than the B747's. At MTOW the aircraft requires a balanced field lenght of only 2000m and reaches the initial cruise altitude of 15.500m and M2 in about half an hour.

The climb and decend are constrainted by the following considerations:

-Minimal Equivalent Airspeed does not drop below 64 m/s EAS (normal to leading edge) to assure safe handling during heavy gust.

-Maximum Equivalent Airspeed does not exceed 130 m/s EAS to assure passenger comfort. If this rule is observed the chance to encounter a 6 m/s^2 acceleration due to gust is only 10% each flight.

-Maximum available thrust between M 1 and M 1.8. At these Mach numbers additional thrust is needed, so the turbine entry temperature will be increased to 1850K for about 15minutes.

Within these limitations a trajectory was determined that would lead to the fastest arrival at cruise height and Mach 2 (fig. 6). The OFW uses 22% of the total fuel available for acceleration and climb, only half of what Concorde needs

Takeoff was estabilished within the FAR36 regulations. To conform with the FAR36st3 regulations the baseline RR Olympus has a bypass flow ratio of 1 and the turbine has been lenghtend accordingly, also the afterburner has been omitted and takeoff is performed at 75% of the maximum thrust.

Emmissions and ozon-layer depletion can be reduced significantly in Comparison to the old Olympus engine when we use the newest GE technology as it was proposed in their variable cycle engine concept.

A maximum sonic boom overpressure of $\pm 69\ N/m^2$ due to supersonic flight was found, a value comparable to Concordes even though the aircraft is much heavier. Such overpressures do not allow supersonic speeds overland. However, the performance characteristics of the aircraft allow economic transportation at the boomless supersonic Mach number of M1.2.

Fig. 8 gives the payload range diagram and the estimated direct operating costs for the 1986 situation. The direct operating costs we calculated using the definition of DOC of ref. 15 and the methodology of ref. 16. In table 4 a breakdown for the DOC is given at the harmonic range. We also plotted the expected revenu based on typical fares.

1.8 Stability and control (W)

Stability and control around the X and Y axis is provided by a 15% multisegmented tailing edge flap similar to the one proposed by NASA for the DLC-cargo transport. (ref. 4) Segmenting the trailing edge flap into little segments increases the reliability of the system and allows the roll-control.

Since it was almost impossible to shift the center of gravity so far forward that we could achieve stability and control at extreme angles of attack (ramp gusts of 15 m/s EAS, 50 ft/s) with conventional flaps, a new two slotted flap design is introduced which can generate at least 30% more lift than conventional plain flaps, both up and down. (fig.9)

The following describes the working of the flap, but it must be noted that the same explanation could be given for a high positive angle of attack if you turn fig. 9 180°):

In the ±12° range the flap is sealed to provide optimum characteristics during ordinary operations. However, at a very high negative angle of attack with the c.g. aft of the aerodynamic center we need a downward flap lift to balance the configuration. If we were to deflect the flap more than 12° up, the flow would separate and we would not increase the flap lift. Therefore the upper spoiler is deflected into the wing structure. The fixed vanes and the flap nose design now enable the flow to move from a high pressure area above the flap to a low pressure area through a slot. This will cause the flow the reattach up to deflections of 25° resulting in a 32% higher lift effectiveness as compared to a typical plain flap. The spoilers of course can also be used during breaking.

Such a flap system could put the neutral point as far back as 37% of the mean aerodynamic chord at OEW and 34 at MTOW, and smooth out any gust peaks.

The artificial stability and control system that controls this flap uses a standard PID (ref. 9) controller. This controller relates the angle of pitch theta and its first and second time derivates to an optimum flap deflection.
In practice, such a system could get very accurate predictions of the aircraft pitch from a Honeywell lasergiro.

For the PID-feedback system developed by the author fig. 7 shows the predicted rearward stability limits when the system is subject to the limit gust as defined by FAR 25.

At Stanford, graduate students under the direction of Elan Kroo made a model of an straight wing with such an artificial stability augmentation system. The model had a proven stability for a center of gravity position at 30% of the mean aerodynamic chord, and had good unsteady aerodynamic characterics.

In the direction of yaw the stability and control is provided by relative thrust settings of the powerplant and by the vertical tailplane rudder as well as the angle of the vertical tailplane as a whole. It remains to be investigated whether such a configuration would work.

Because the OFW can vector the thrust to compensate cross drag it does not need a bank angle to make sidewind landings.

1.9 Conclusions (W)

The oblique flying wing SST, as presented in this paper combines low structural weight, high aerodyamic Lift-to-Drag ratios from subsonic speeds to Mach 2.

If the flying wing is to accommodate passengers a minimum size is required. A minimum size oblique wing would seat 350 passengers have a planform of 1100m², an ellipse ratio of six and a Wp/Wto of 12%. The OFW as presented here seats between 460 and 540 passengers, is slightly larger and has a 20% higher payload fraction.

As compared to contemporary subsonic aircraft of the same size its operational characteristics are superior. The aircraft can fly at the same holding speeds as todays subsonic transports, and requires only half the takeoff field length.

A 1980's state of the art stability augmentation sytem that actuates a new flap design could provide safe handling characteristics and smooth out gusts to acceptable levels.

The total cost of development of the aircraft is going to be higher than of any other aircraft sofar (10 billion ('86)USD), but due to the high blockspeed the direct operating costs of the aircraft are going to be comparable to the B747's.

It is therefore proposed that further research is done to validate the results presented in this study and to expand the database on oblique flying wing configurations.

1.10 Aknowledgements (W)

The author wishes to thank the fluid dynamics division of NASA AMES under dr. Paul Kutler and prof. Holt of the UC-Berkeley department of Mechanical engineering without whom this study could not have been completed. He is also grateful for the stimulating conversations with dr. Jones of Los Altos and the lasting contributions of prof. Torenbeek of Delft University of Technology in his work.

1.11 Objectives (W)

This paper is presented to summarize approximately 600h of research on an oblique supersonic transport aircraft since June 12th. in anticipation of a final contractor-report published in 1988.

It will also serve as a bases for the evaluation of the research grant between NASA AMES and Stanford that is to succeed the current NAG-2-471 contract.

Finally this paper aims to expand the support for the oblique supersonic transport aircraft.

1.12 References (W)

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1.13 Table 1: Technical describtion (W)

Dimensions.
external:

Wing span	122.00	m.	
Wing chord root	15.25	m.	
Wing aspect ratio	10.16		
Height overall	17.00	m.	
Cabin max. external thickness	2.15	m.	
Vertical tail			
span	10.0	m.	
aspect ratio	1.4		
Wheel track	44.0	m.	(unyawed)
Wheel base	8.52	m.	
Wheel size	40x14"		(6 legs)
Passenger door (2 in floor nose)			
Height	1.00	m.	
Width	1.00	m.	
Emergency exit (8 in cabin ceiling)			
Height	1.00	m.	
width	0.50	m.	
Baggage door (2 in floor baggage holds)			
Height	1.60	m.	
Width	2.33	m.	

Dimensions Internal.

Cabin:

Length incl. galley toilet and baggage compartment)	62.0	m.
Length passenger cabin	44.4	m.
Maximum width	7.2	m.
Maximum height	1.95	m.
Floor area pax.cabin	300	m2.
Volume passsenger cabin	534	m3.
Volume freight holds	2x50	m3

Areas

Wing	1461	m2.
Vertical tail area	70	m2.

Weights:

Maximum takeoff mass	302000	kg.

Maximum operating empty mass	137300 kg.
Harmonic payload, 35"pitch	43700 kg.462pax no cargo
Maximum payload	67300 kg/540pax 16ton cargo
Harmonic fuel mass	121000 kg.
Maximum fuel mass	139400 kg
Maximum landing mass	187000 kg.

Performance:

max cruise mach number:	Mach 2 (2124 km/u)
start cruise altitude:	16000 m.

Harmonic Range with IFR reserves at max cruise speed:
9000km

Long range overland cruise speed
Mach 1.2 (1250 km/u)

Takeoff procedure:	zoom-start, no flaps wing at 4.5°incidence
Balanced field length @mtow	≈2050 m.
dg2 (one engine out 10.5 m)	6.6%
Rigid runway LCN	79
V2	87 m/s
Vmin.contol @mtow	80 m/s (37°sweep)
Sideline noise:	104 db EPNl
Max. climb speed (SL)	34 m/s
W/Smax	2.0 KN/m^2
T/Wmax	0.35

Max. sea-level sonic boom pressure rize at 16200m and Mach 2:
69 N/m2

1.14 Table 2: Mass breakdown (S)

Mass breakdown for the harmonic range

group	item	mass	xcg	Sx	xcg/cref
Structure					
	midsection (cabin)	21.980	5.600	123.088	
	outboard panels	23.590	4.400	103.796	
	flaps	4.820	13	62.660	
	vertical tail	3.017	8	24.136	
	gear	13.660	5.600	76.496	
	surface controls	2.148	7.780	16.711	
	nacelles (4),incl. pivot	9.531	3.800	36.218	
	total:	78.746		443.105	
Powerplant	(4 dry engines, 250KN each)				
	gasgenerator: 4 x 3.07	12.280			
	fan: 4 x 1.01	3.027			
	jetpipe: 4 x 0.64	2.557			
	thrust reverser: 4 x 0.80	3.216			
	fuel sytem:	.692			
	total	21.771	3.800	82.731	
Systems+equipment					
	apu	.305	8.380	2.556	
	instruments	2.766	2	5.532	
	hydraulic+pneumatic	2.218	5.896	13.076	
	electrical	2.216	4.190	9.287	
	furnishings+equipment	17.720	4.700	83.284	
	airconditioning+anti-icing	1.746	3.960	6.915	
	total	26.971	5.800	120.650	
	DEW	127.489		646.486	.333
Operational items					
	crew provisions	1.206	3.900	4.703	
	passenger supplies	6.930	3.900	27.027	
	residual fuel+oil	.407	3.600	1.466	
	miscellaneous	1.275	6.800	8.669	
	total	9.818		41.866	
	OEW	137.307		688.352	.329
Payload					
	passengers	35.574	4.700	167.198	
	luggage	8.316	4.700	39.085	.324
Fuel					
	tripfuel	109.830	3.600	395.388	
	reserve fuel	11.340	3.600	40.824	
MAXIMUM TAKEOFF MASS		302.367 kg		4.401	.289
		671.926 lbs			

1.15 Table 3: Drag breakdown at cruise (S)

Drag breakdown at M=2, CL=0.068 h=16000m

Drag Comp		Drag Coefficient
Fiction	Wing	.0028
	Tail	.0002
	Nacelle	.0002
Wave	Total Including roughness, Engine installation.	.0022
Lift	Total	.0015
Total	Drag Coefficient	.0069
	(L/D)start cruise	9.80

Table 4: Aircraft economy (1984 conditions)

Development cost of the airframe: 8.40 G$
OFW Development cost of the engines: 1.97 G$

OFW unit price for a break-even number of 200: 409 M$
B747 price in 1984: 103 M$

Cost of fuel:	85 cts/gallon
Range:	9000km/ 5.6h blocktime
Number of passengers:	OFW: 462 @34"pitch B747:452 @34"pitch
Block-to-blockspeed	1599 km/h
Utilization 747 and OFW:	blocktime=4500 h/year
Depreciation:	14 years to ten percent
Insurance:	1% of aircraft price

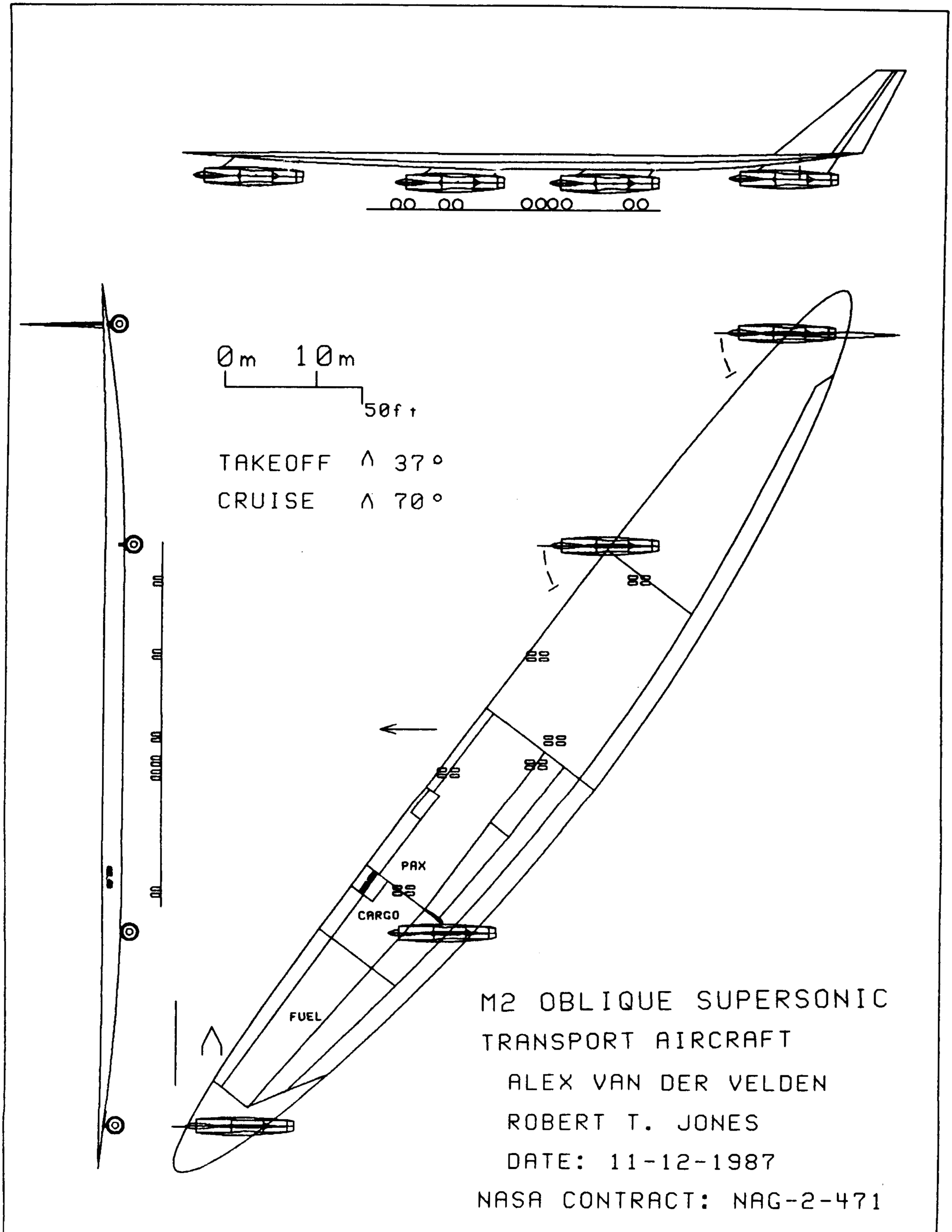
-----OPERATING COSTS---------

Item	OFW/nbe=200 (Vb=1599km/h) /km	/blockhour	B747 (ref.12) (Vb=755km/h)	
flightcrew	0.46	750	1.00	750
fuel/oil	3.61	5774	3.60	2719
ownership/insurance	3.76	6020	2.27	1896
Maintenance:				
Airframe	0.35	562	0.34	255
Engine	0.59	936	0.30	226
Burden	0.18	283	0.52	395
DOC	8.95		8.26	$/km
DOC/km	1.93		1.82	$cts/paxkm
additional fare:	0.62		0	$cts/paxkm

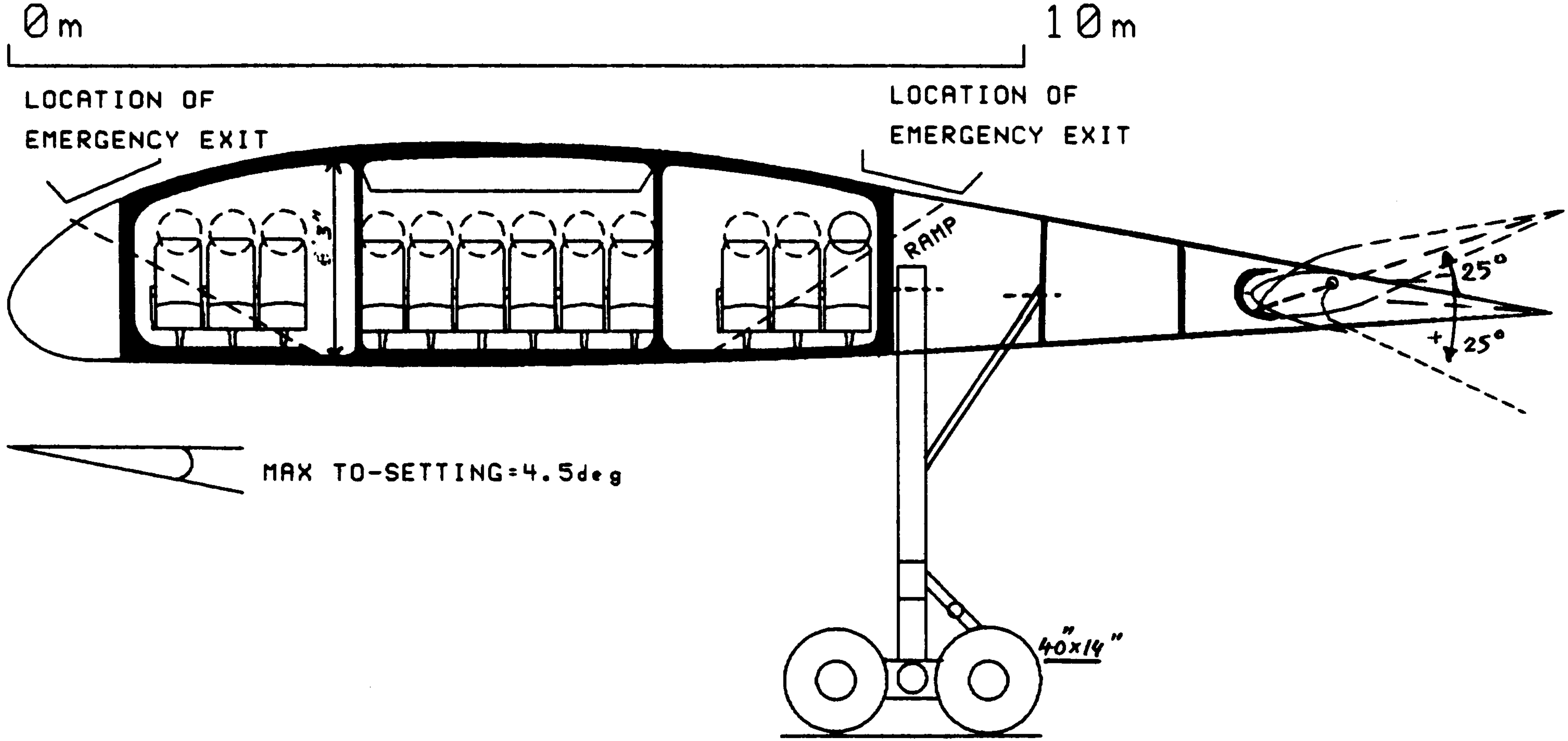
As expected the cost of ownership of the aircraft + parts is much higher for the OFW than for the B747, the other items are a bit less resulting in a Direct Operating cost just slightly above the B747's.
We have calculated the acceptable increase in fare by using the average US income of $9,00/h as the passenger's opportunity cost of time.

-----MAXIMUM ANNUAL PRODUCTION-------

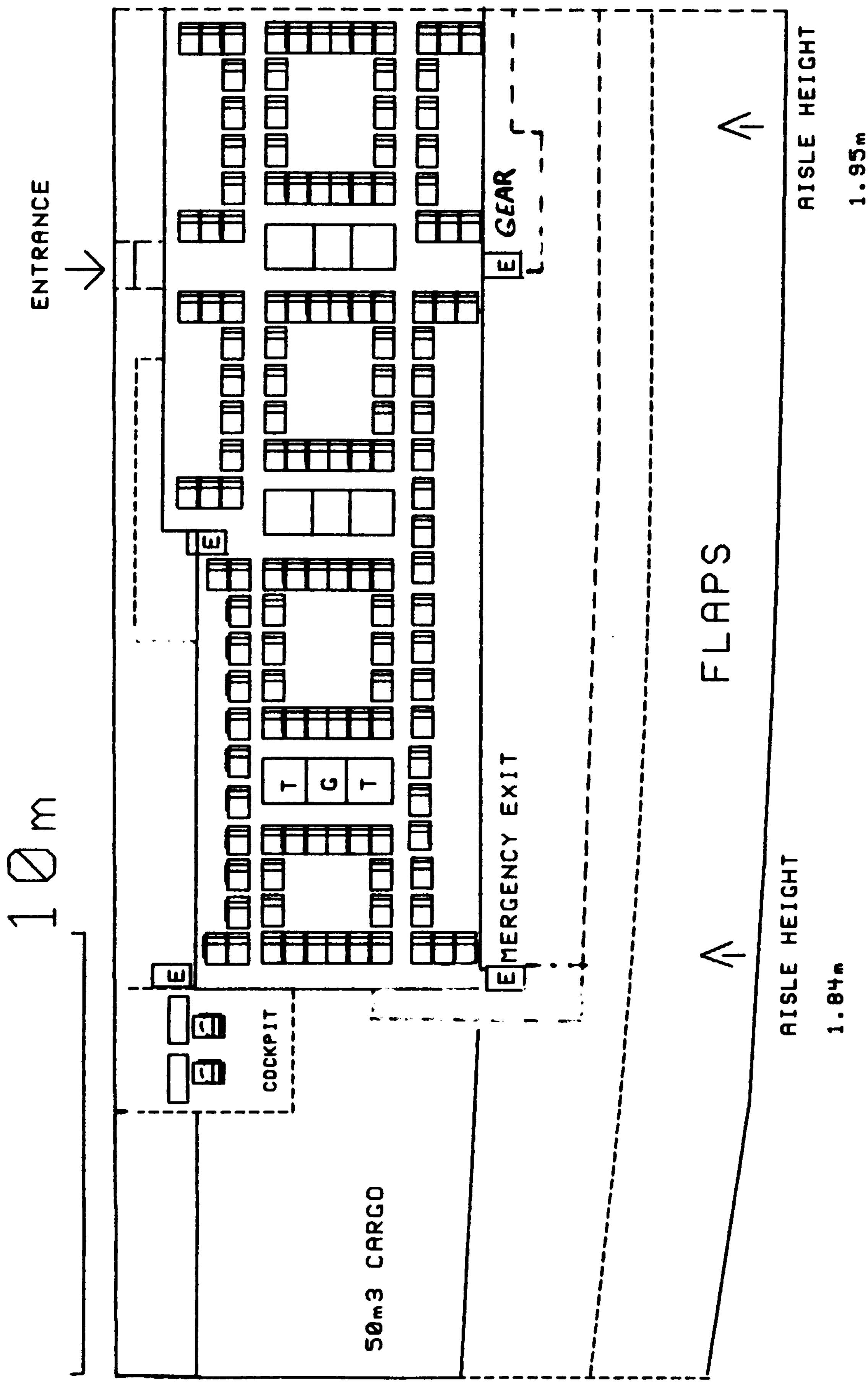
OFW	3.35e9 passenger kilometers @±6% higher fare
B747-100B	1.53e9 passenger kilometers


0m 10m
50ft
TAKEOFF Λ 37°
CRUISE Λ 70°
PAX
CARGO
FUEL
Λ
M2 OBLIQUE SUPERSONIC
TRANSPORT AIRCRAFT
ALEX VAN DER VELDEN
ROBERT T. JONES
DATE: 11-12-1987
NASA CONTRACT: NAG-2-471

CABIN CROSS-SECTION



CABIN LAYOUT



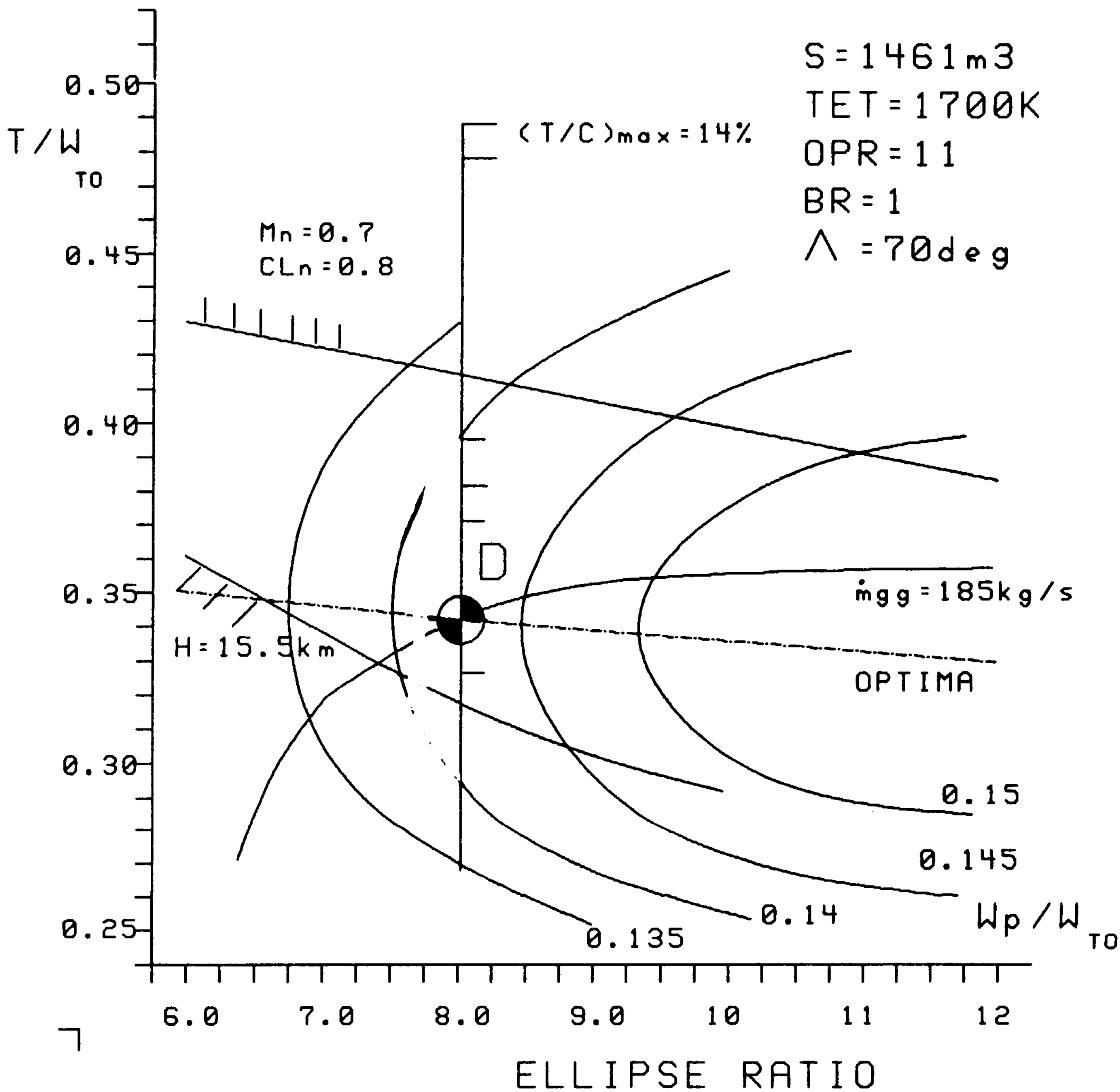


FIG.3: WING ELLIPSE RATIO AND THRUST LOADING OPTIMIZATION

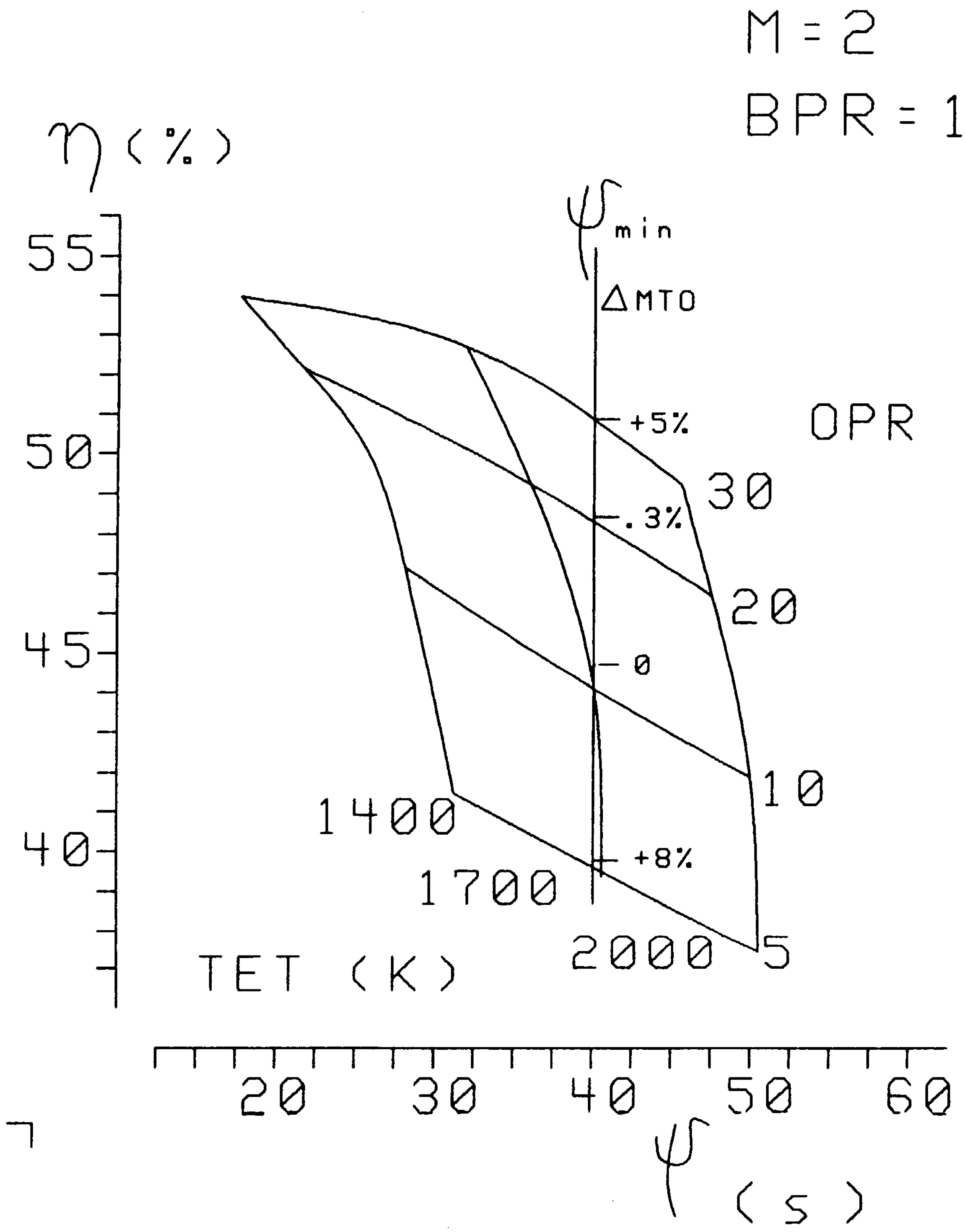


FIG. 4: OPTIMIZATION OF THE ENGINE CYCLE

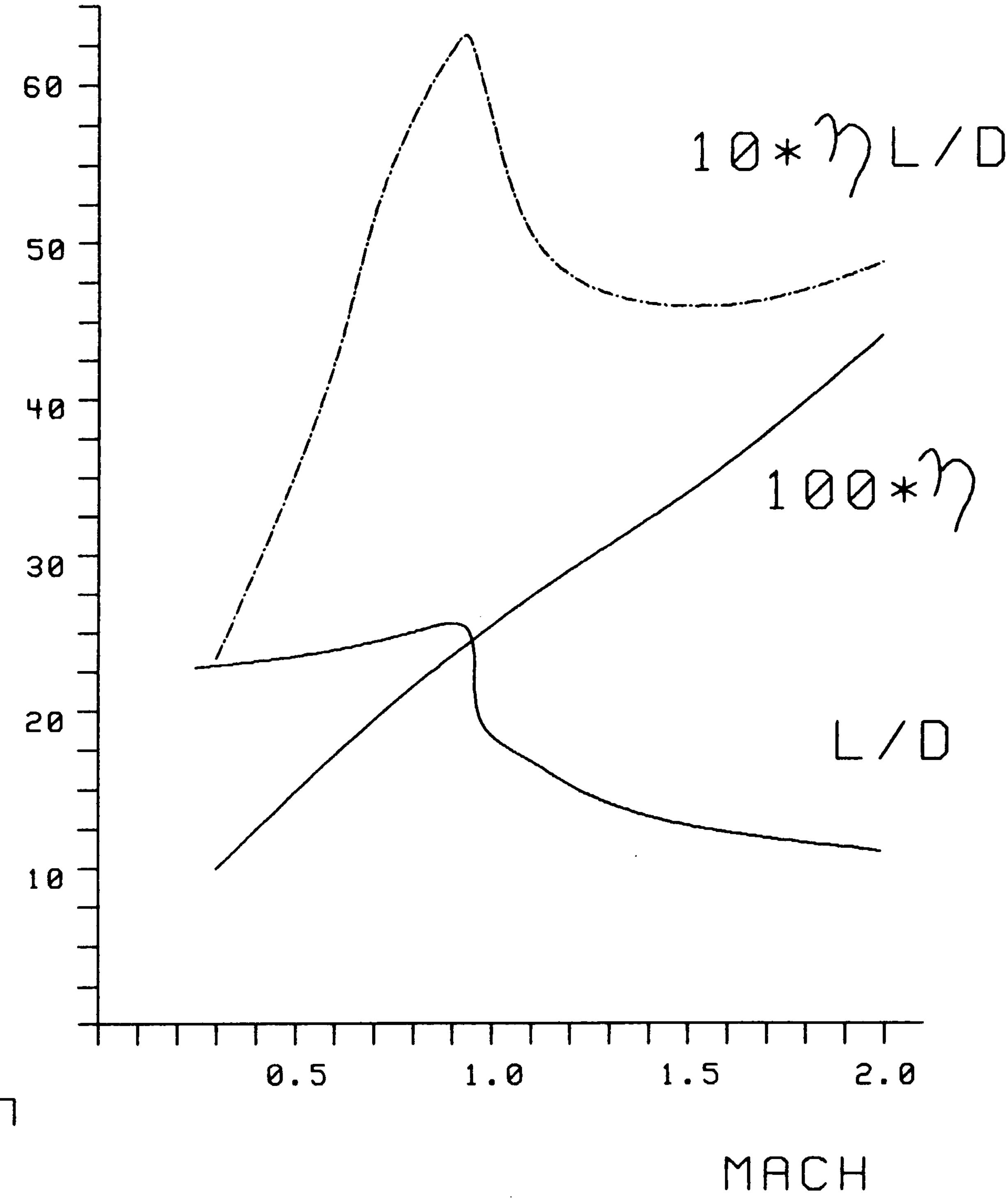


FIG. 5: VARIATION OF THE MAXIMUM L/D RATIO AND THE MAXIMUM OVERALL ENGINE EFFICIENCY WITH MACH NUMBER

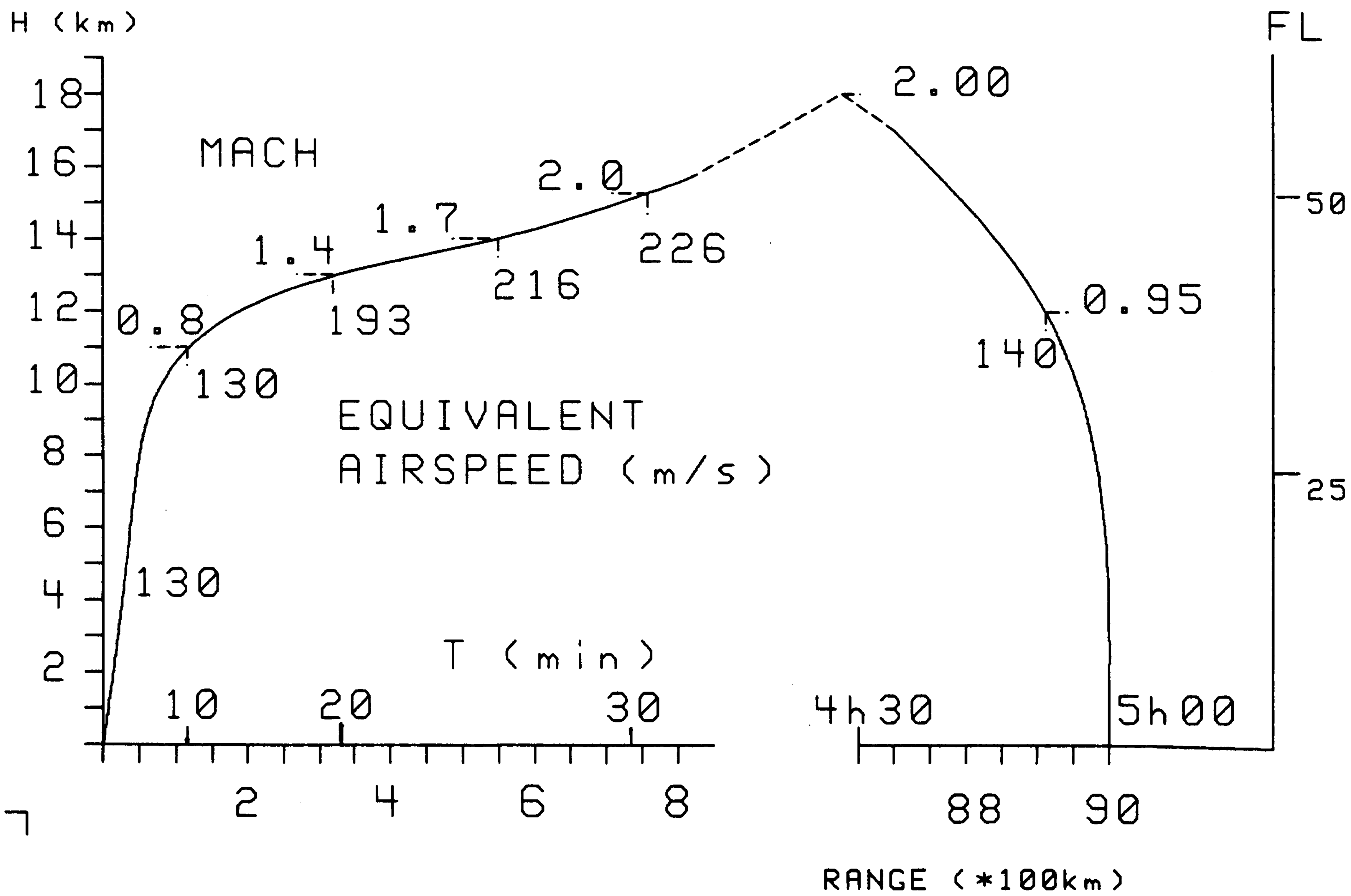


FIG. 6: FLIGHT PROFILE

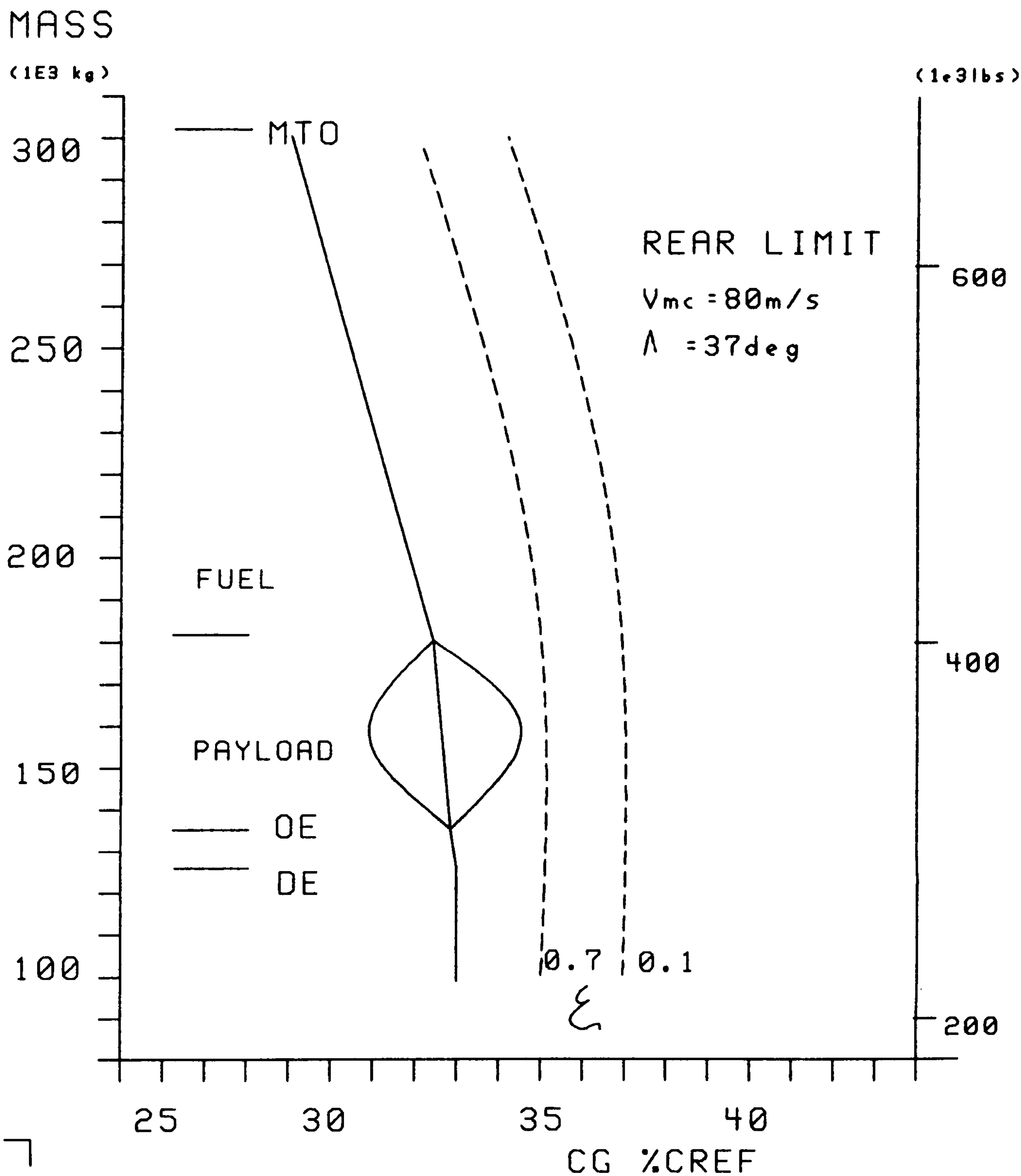


FIG. 7: LOAD AND BALANCE DIAGRAM WITH CRITICAL SAS-LIMITS

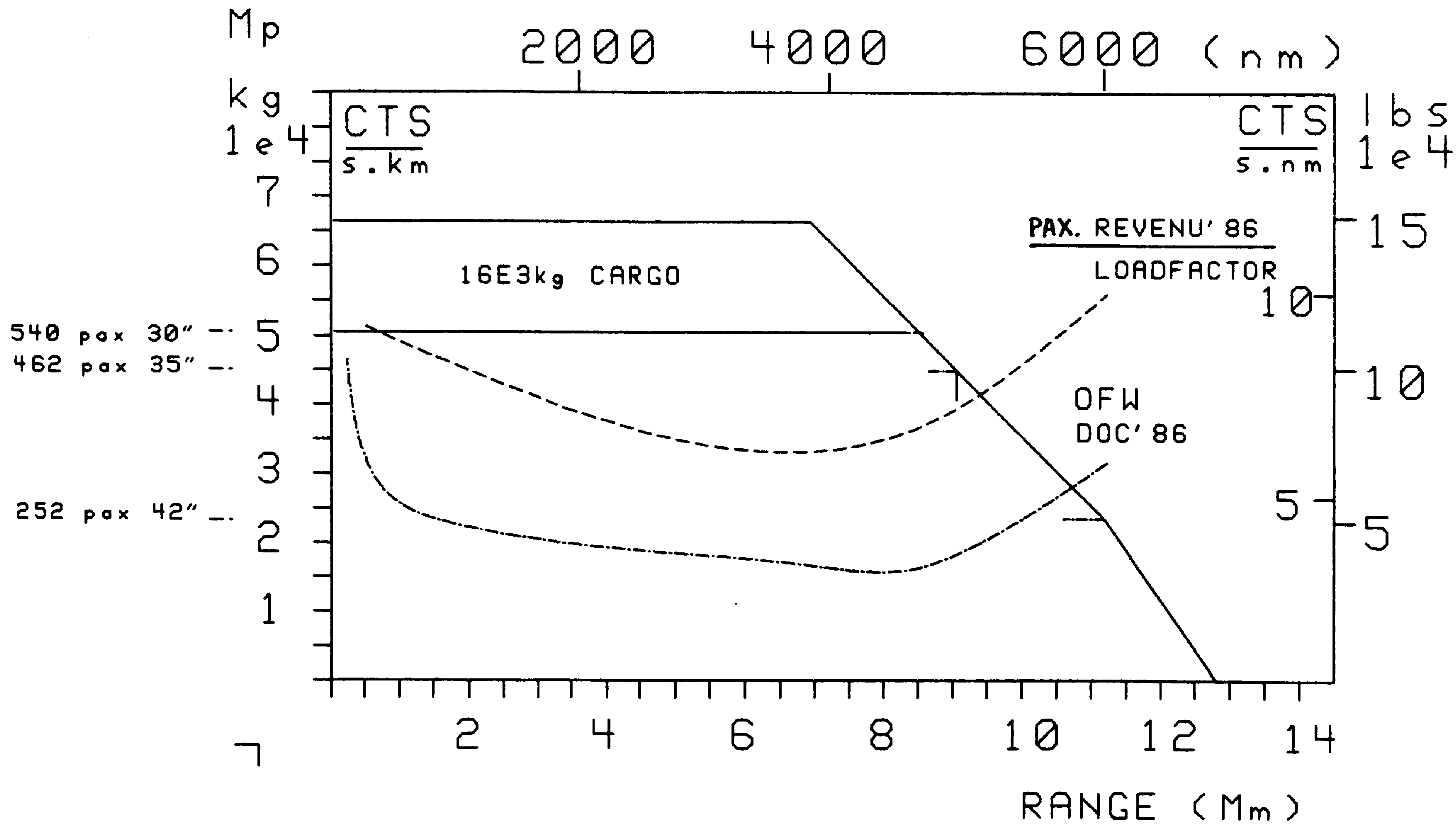


FIG.8: THE PAYLOAD RANGE DIAGRAM AND THE DIRECT OPERATING COSTS

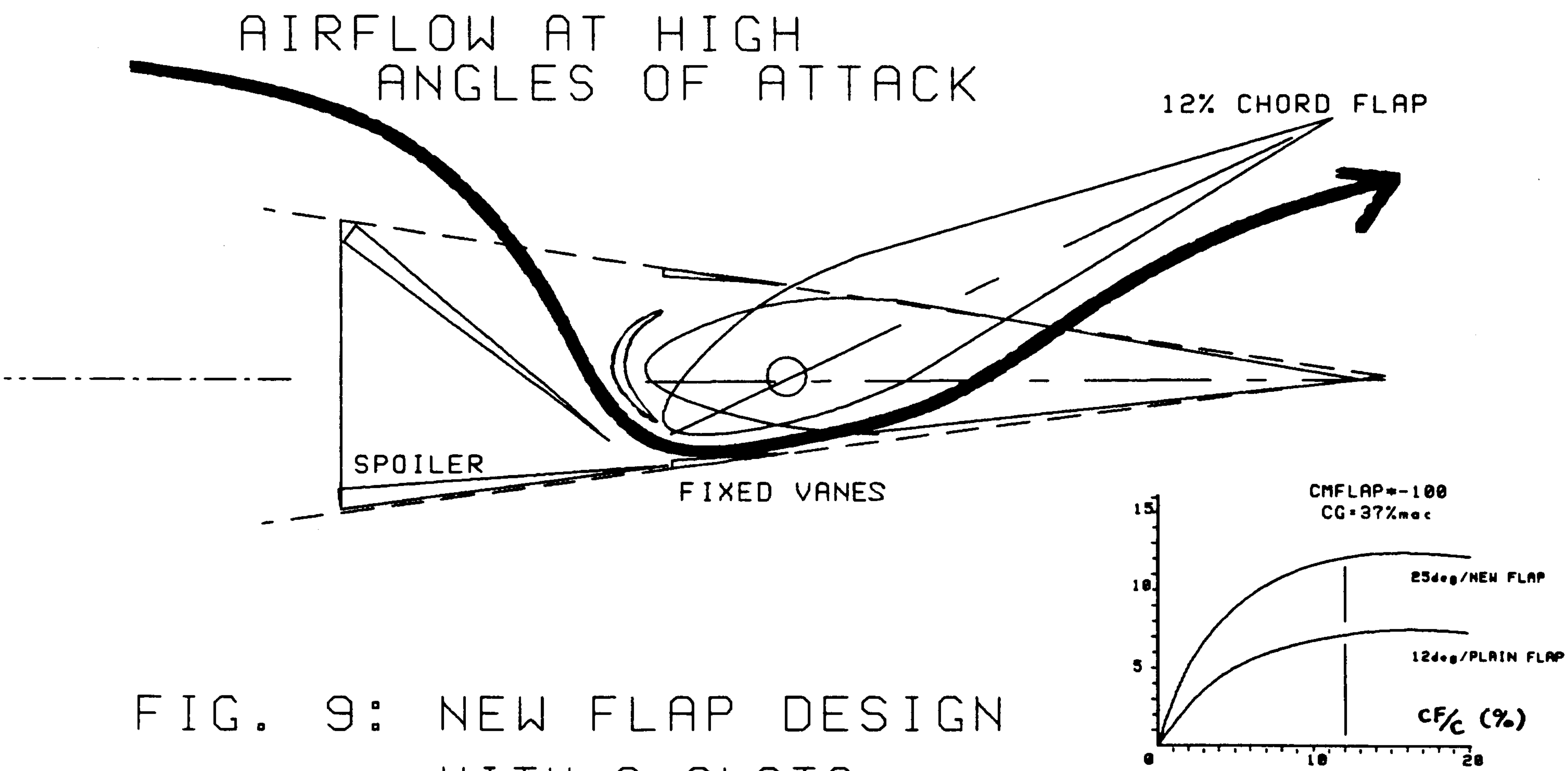


FIG. 9: NEW FLAP DESIGN
WITH 2 SLOTS